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EMB Working Group: Ocean oxygen

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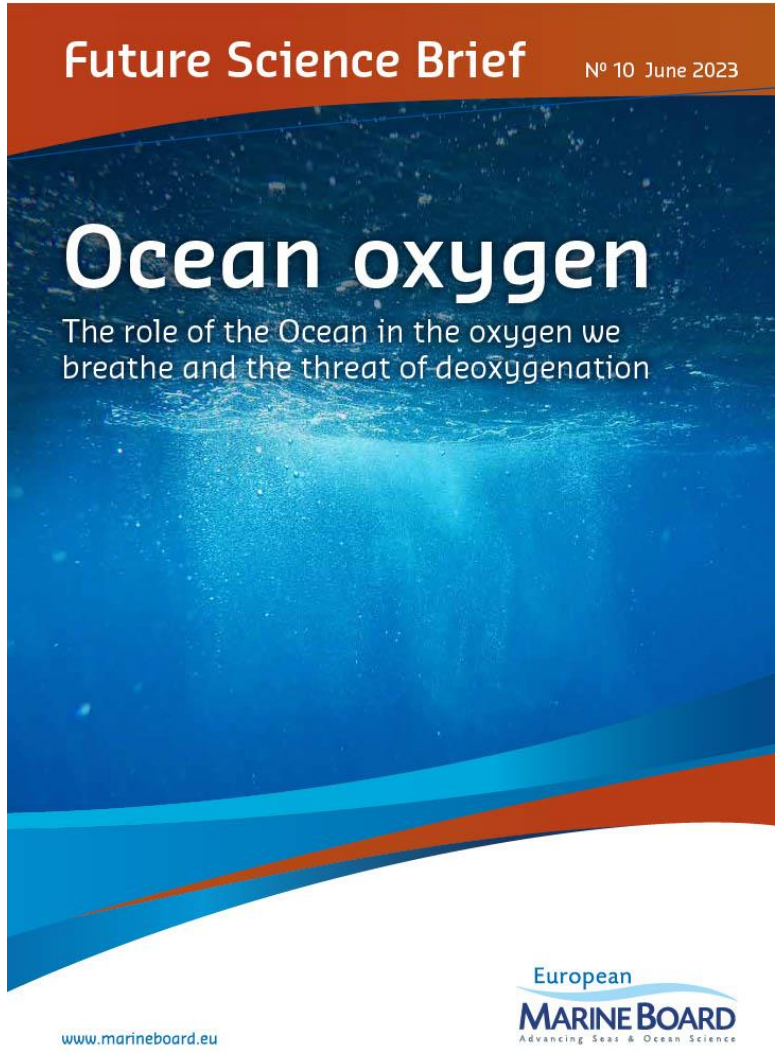
Future Science Brief N°10: Ocean oxygen



Ocean oxygen

The role of the Ocean in the oxygen we breathe and the threat of deoxygenation

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What does the document cover?

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1. Introduction: importance of Ocean oxygen
2. History of oxygen on Earth and relationship to life
3. The modern oxygen cycle: oxygen in the atmosphere and in the Ocean
4. Current Ocean deoxygenation and impacts
5. Methods to study Ocean oxygen
6. Addressing Ocean deoxygenation through mitigation and adaptation
7. Recommendations for policy, management and research

The document is aimed at policy makers, research funders and scientists

→ Written to be understandable by a wide audience

Importance of Ocean oxygen

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Is there public awareness?

Importance of Ocean oxygen

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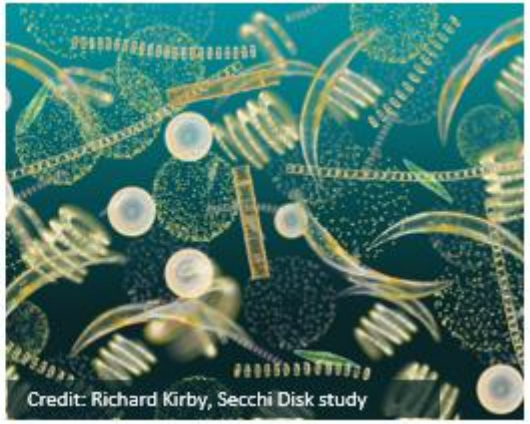
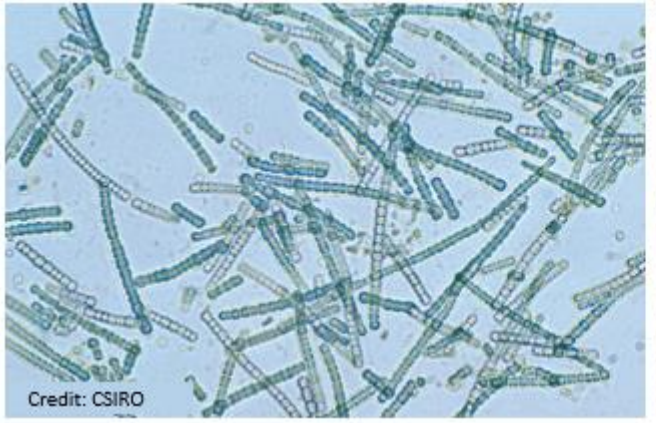
Is there public awareness?

- **General awareness** that the **Ocean produces oxygen**
  - But **some erroneous conceptions** on the role of the Ocean in the oxygen humans breathe
    - e.g. "*every second breath you take comes from the Ocean*"

- **Low awareness** of the problem of **Ocean deoxygenation**
  - e.g. in comparison with Ocean acidification or warming sea temperatures

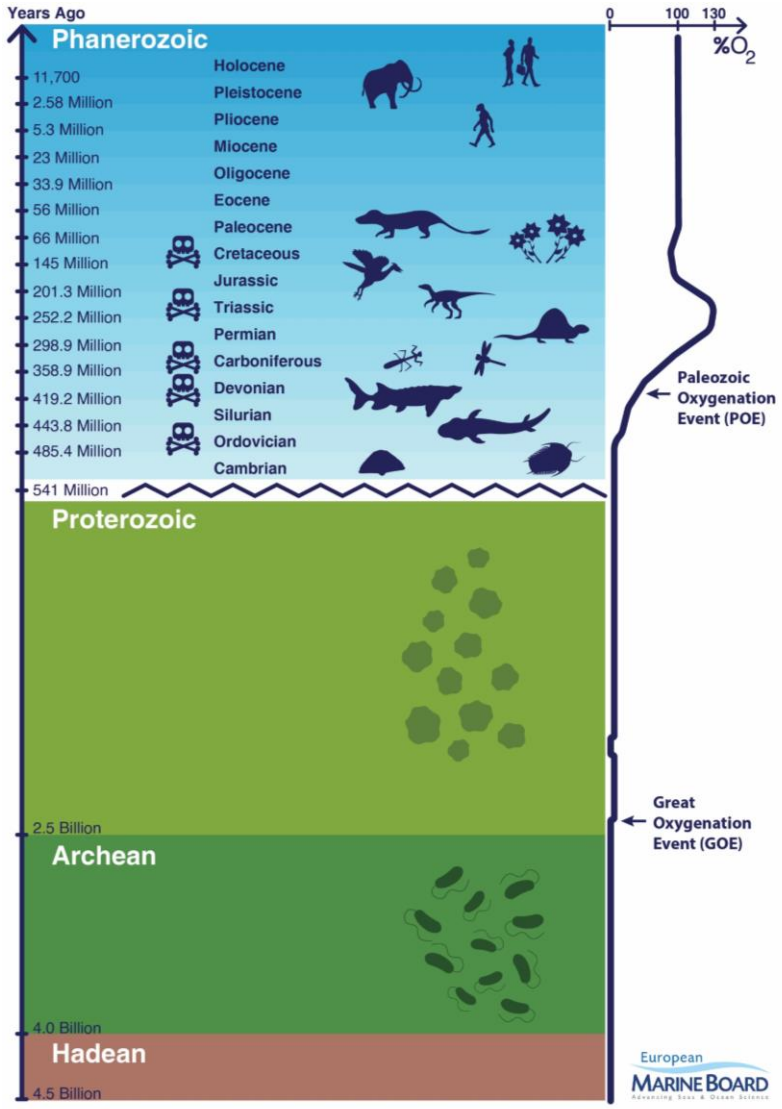

Credit: Stefan Andrews, Ocean Image Bank


Credit: Richard Kirby, Secchi Disk study


Credit: CSIRO


Credit: Ben Jones, Ocean Image Bank

History of oxygen on Earth



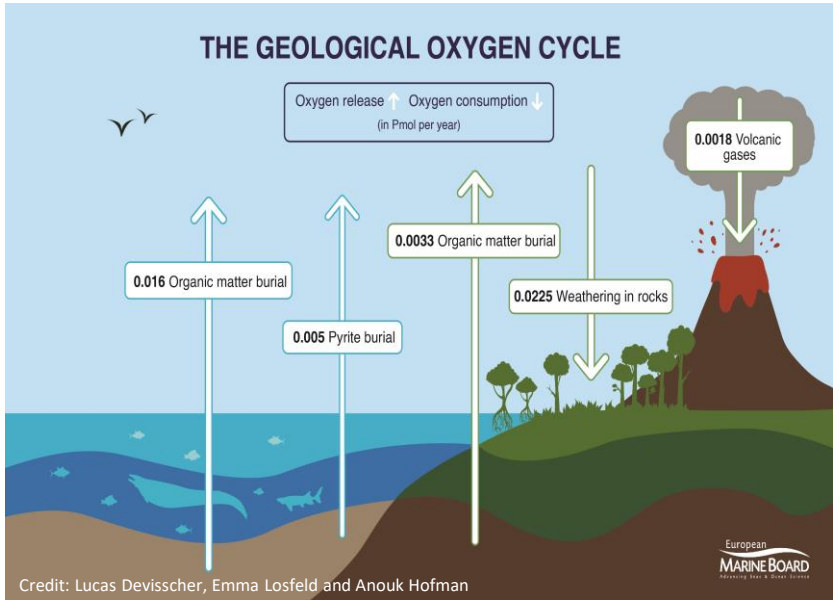
Credit: Lucas Devisscher, Emma Losfeld and Anouk Hofman, Arteveldehogeschool

- For **most of Earth's history: almost no free oxygen (O_2)** in the atmosphere or the Ocean
- **Great Oxidation Event (GOE)**: oxygen-producing **cyanobacteria** (i.e. blue-green algae) evolved & oxygen started accumulating in the Ocean and atmosphere
- **Paleozoic Oxygenation Event (POE)**: another drastic increase in oxygen, due to **evolution of land plants**
- At least **three out of five mass extinctions** were **associated with Ocean deoxygenation**
- Numerous **feedbacks stabilise oxygen** content of the **atmosphere**

Oxygen accumulation in the atmosphere:

- **Burial** of **organic matter** and **pyrite** (mineral) creates a small imbalance between oxygen production and consumption
  - ➢ Oxygen escapes respiration and can accumulate in the atmosphere (**over geological time**)

86% of the oxygen humans breathe (6 of 7 breaths) came from the Ocean over geological time scales



Credit: Lucas Devisscher, Emma Losfeld and Anouk Hofman

The modern oxygen cycle

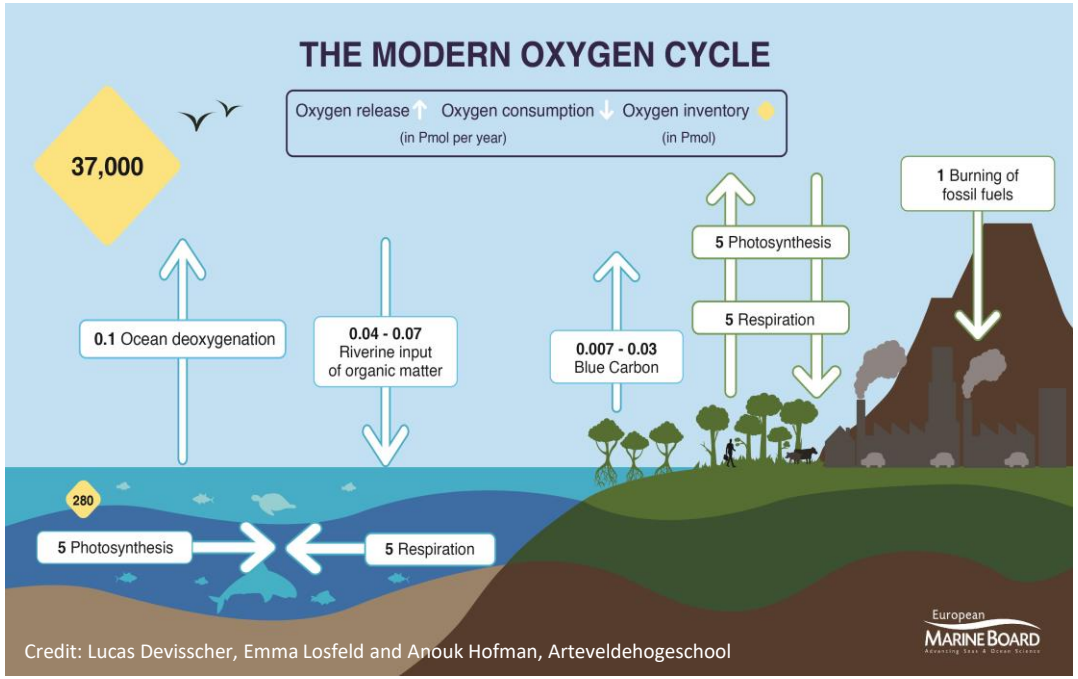
Oxygen

- **In the atmosphere:** is **very homogeneous**ly distributed
- **In the Ocean: very large differences** in concentration (both geographically and throughout the water column)
  - Differences are **due to physical processes** (e.g. currents, the amount of oxygen seawater can hold) **and biological processes** (e.g. photosynthesis, respiration)
  - Some areas in the Ocean have persistent, very low oxygen concentrations due to natural processes

Current oxygen production on Earth:

- The land and Ocean each **produce** about 50% of Earth's oxygen
- **Almost all this oxygen is consumed again** (respired) by terrestrial and marine organisms, respectively

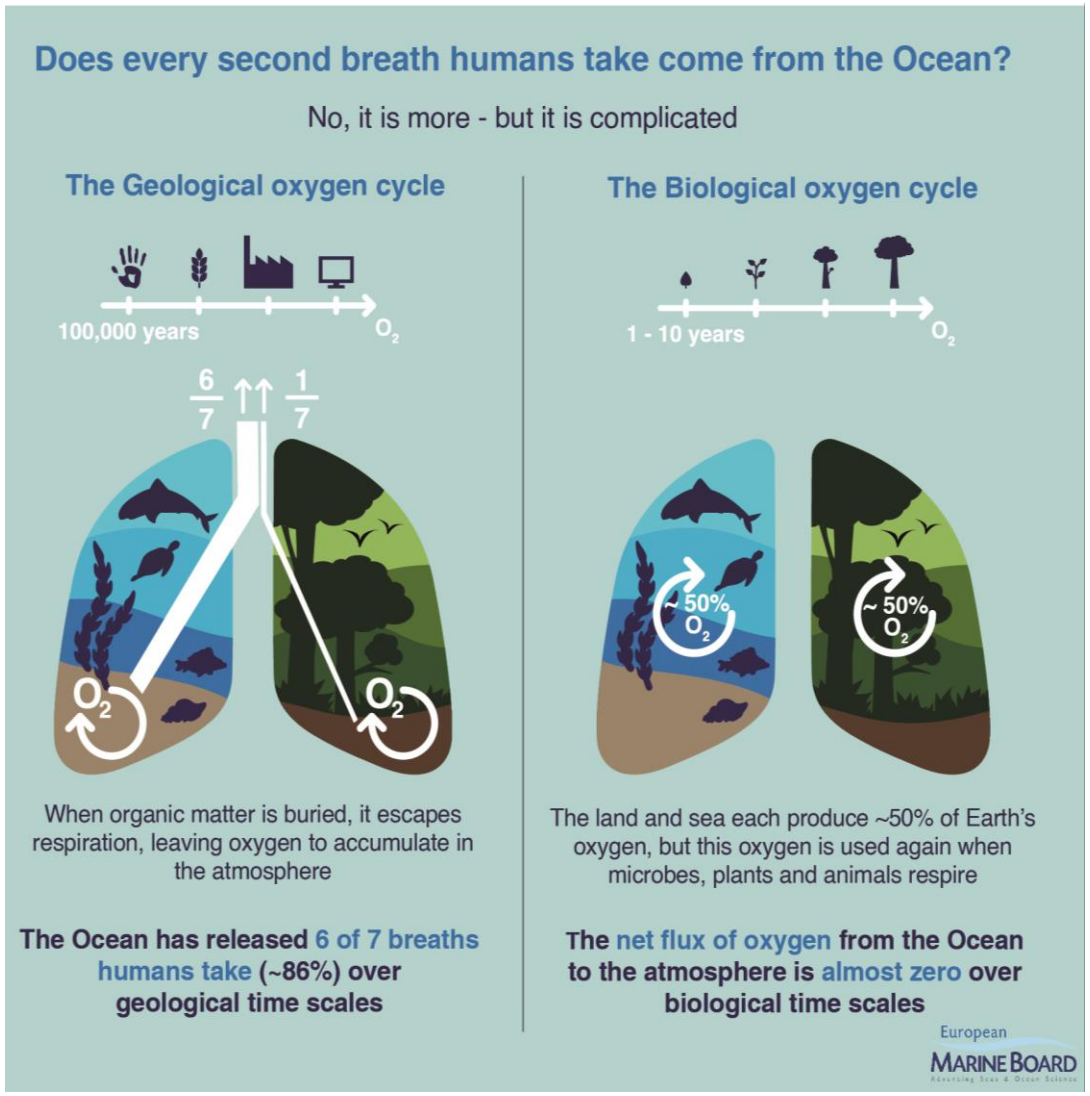
  → **virtually** no net accumulation of oxygen in the atmosphere or Ocean



>99% of all freely available oxygen (O_2) is in the atmosphere

<0.01% is in the Ocean

Does every second breath we take come from the Ocean?

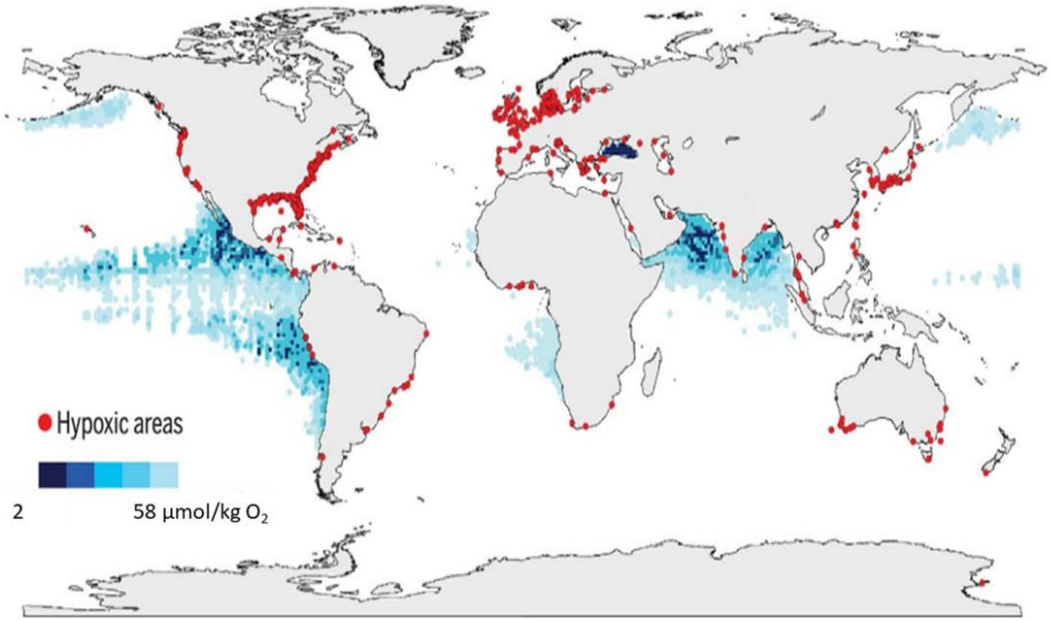


Credit: Lucas Devisscher, Emma Losfeld and Anouk Hofman, Arteveldehogeschool

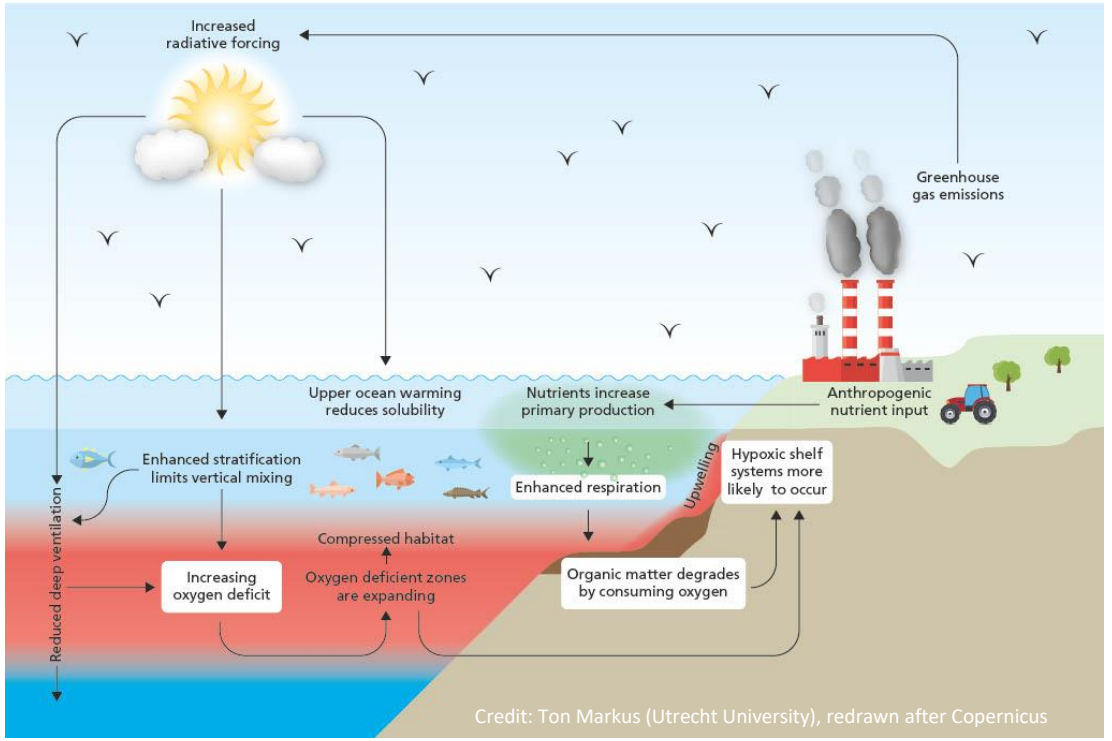
- ✓ The Ocean produces ~50% of Earth's oxygen
- ✓ Every second breath taken by all life on Earth comes from the Ocean
- ✓ Since the origin of life on Earth, the Ocean has provided most of the oxygen in the atmosphere, and is responsible for 6 of 7 breaths humans take

Ocean deoxygenation

- The **Ocean** has been **losing oxygen since the 1950s**
- **In open Ocean**: oxygen loss is **primarily due to** physical changes due to **human-induced climate change**
- **In coastal waters**: the **main cause** is **excessive anthropogenic nutrient input** (run-off from agriculture)



Breitburg *et al.* 2018



Breitburg *et al.* (2018) Declining oxygen in the global ocean and coastal waters. Science, 359(6371), eaam7240. https://doi.org/10.1126/science.aam7240

Ocean deoxygenation

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Consequences

Biogeochemistry:

- Low oxygen levels **alter the biogeochemical cycling of many elements** in the marine environment that are important for life
- Low oxygen levels **promote** the **production of the greenhouse gases** nitrous oxide and methane
- Biogeochemical **feedbacks enhance oxygen loss** in marine systems

Marine life and ecosystems:

- **Strongly impacts life in the Ocean**, e.g.:
  - Habitat loss
  - Shifts in species distribution
  - Major changes in biodiversity, food-web interactions and ecosystem structure
  - Acute or chronic low oxygen levels can result in mass mortality
- **Diminishes marine ecosystem services**, e.g.:
  - Degraded water quality & reduction of aesthetic/cultural value
  - Displacement/ reduction of fisheries resources
  - Impacts the Ocean's carbon storage and uptake mechanisms

Methods to study Ocean oxygen

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Observations

- **Technological advances** (e.g. sensor development and autonomous platforms) have increased capabilities to observe Ocean oxygen:
  - e.g. continuous measurements and increased spatial coverage
  - **More observations are needed** and some areas are under-sampled

- The scientific and societal **need to study Oxygen Deficient Zones** (ODZs) and their variability is driving technological advances
  - Observing and modelling very low oxygen concentrations **remains challenging**

- **Seabed sediments record the history of deoxygenation** dating back millions of years (paleo data)
  - **Paleo oxygenation data sets** from the geological past are **still scarce and scattered**

Methods to study Ocean oxygen

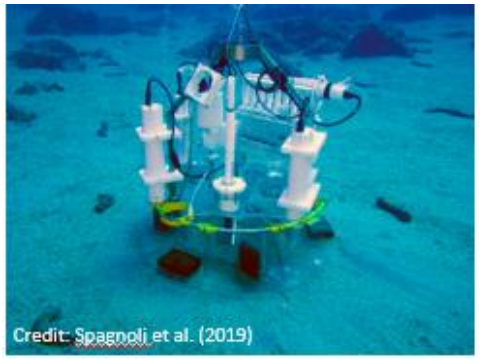
Modelling

Global models

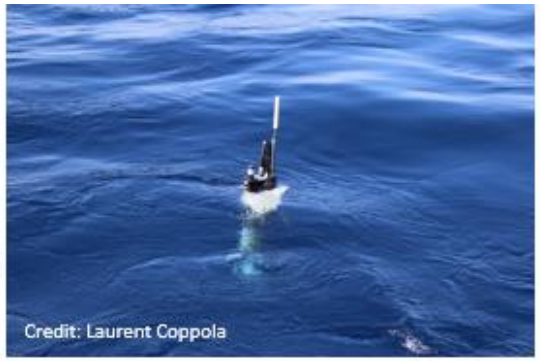
- **Earth System Models (ESMs)** are **powerful to assess** the consequences of **different scenarios** for the land and Ocean
  - **Accurately representing oxygen variations** in ESMs **is challenging**

Coastal models

- **Coastal models** can support the **implementation of regional management strategies**, such as managing excessive nutrient run-off leading to oxygen deficiency
  - **To improve** these **models**, **more data are needed** (at higher spatial and temporal resolution) on atmospheric conditions & riverine inputs of nutrients and organic matter


Credit: Spagnoli et al. (2019)


Credit: Ines Bartl


Credit: Laurent Coppola


Credit: the Argo Program

Mitigation and adaptation needs

- **Limiting global warming will** (according to current models) **stop upper Ocean deoxygenation**
  - For this, it is **key to reach net-zero anthropogenic greenhouse gas emissions**
- **Coastal deoxygenation can be efficiently reduced** in many regions by **limiting terrestrial run-off of nutrients and organic waste**
  - Important to **implement management strategies**
- **Blue carbon coastal ecosystems** **can help** **oxygenate coastal waters** and thereby reduce the impacts of deoxygenation
  - Mitigation is **restricted to small near-shore habitats** where these species can grow
  - These **habitats** are **also impacted by human activities**


Credit: Marine Scotland

Mitigation and adaptation needs

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- **Engineered addition of oxygen** into Ocean regions that would otherwise experience critical oxygen loss **has been proposed** and **may help to locally increase oxygen levels**
  - **Likely at the expense of non-local side-effects** that may **even accelerate global Ocean deoxygenation**
  - **Better knowledge is required**
- The **deep-sea** **is already experiencing deoxygenation** as a **result of previously emitted greenhouse gases** and **will continue losing oxygen for centuries**
  - **Reducing other stressors** on deep-sea ecosystems & **increase protection** **to enhance resilience**


Credit: MARUM – Center for Marine Environmental Sciences, University of Bremen


Credit: Pia B, Pexels

Recommendations

Recommendations for policy and management

- Recognise **Ocean deoxygenation** as a **major threat**
- Reach **net-zero greenhouse house gas** emissions to **stop upper Ocean deoxygenation**
- Limit **run-off of nutrients** and organic waste to **reduce coastal deoxygenation** and hypoxia
- Reduce stressors and **increase protection of marine ecosystems**, **especially in deep-sea ecosystems**, to **increase resilience**
- **Include Ocean oxygen in future projections** by intergovernmental bodies (e.g. **IPCC, IPBES**) and in high-level frameworks for planetary health (e.g. **SDGs**) to **spur action and societal awareness**
- **Promote the following statements** on the role of the Ocean in the oxygen we breathe, to provide the most accurate information:
  - ✓ The Ocean produces ~50% of Earth's oxygen
  - ✓ Every second breath taken by all life on Earth comes from the Ocean
  - ✓ Since the origin of life on Earth, the Ocean has provided most of the oxygen in the atmosphere, and is responsible for 6 of 7 breaths humans take

Recommendations

Recommendations for funders, research and monitoring

- Fund and perform research to better understand **historical, current and future Ocean deoxygenation rates**
- Fund and perform research to enhance understanding of the **biological, chemical and physical processes controlling oxygen dynamics**
- Increase **Ocean oxygen observations and modelling efforts**
- Ensure that **all oxygen data is compiled and shared**, feeding into **global databases**, to accurately document and predict Ocean oxygen changes
- Develop **new low-power and low-cost oxygen sensors**
- Include **oxygen in multiple stressor studies** of marine environments
- Fund and perform research to better understand **how deoxygenation will impact marine life**, from populations to ecosystems
- Fund and perform research to better understand the **vulnerability of ecosystem services, our society and our economy to deoxygenation**